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Honeywell

(NASA-CR-171126) RESEARCH PRESSURE
INSTRUMENTATION FOR NASA SPACE SHUTTLE MAIN
ENGINE, MODIFICATION NO. 6 Monthly Progress
Report (Honeywell, Inc.) 21 p HC A02/MF A01

N84-32780

CSCL 14B G3/35 00738

Unclass

RESEARCH PRESSURE INSTRUMENTATION

FOR

NASA SPACE SHUTTLE MAIN ENGINE ✓

NASA CONTRACT NO. NAS8-34769

MODIFICATION NO. 6

MONTHLY REPORT

GEORGE C. MARSHALL SPACE FLIGHT CENTER

MARSHALL SPACE FLIGHT CENTER, ALABAMA 35812

MARCH 1984

Prepared By:

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HONEYWELL INC.
SOLID STATE ELECTRONICS DIVISION
CONTRACT NO. NAS8-34769
MODIFICATION NO. 5

RESEARCH OF PRESSURE INSTRUMENTATION FOR NASA SPACE SHUTTLE MAIN ENGINE

Monthly R & D Progress Report March 1984 - Report No. 6

A. Technical Progress and Plans

- See attachment 'A'

B. Schedule

- See attachment 'B'

C. Status of Funds

	<u>LBM</u>
Total Baseline Plan	\$407,350
Total Funded	\$300,000
Cost Incurred to 4/01/84	\$199,043
Inception to Date Plan	\$192,652*
Estimate at Completion	\$407,350

D. Estimated percent of physical completion: 49%

E. At the present time the comparison of the cumulative costs to the percent of physical completion does not reveal any significant variance requiring explanation.

* The "Inception to Date Plan" numbers reported for January and February were incorrect. These reports should be corrected as indicated below:

	<u>January</u>	<u>February</u>	<u>March</u>
- Cost Incurred	\$107,500	\$169,179	\$199,043
- Inception to Date Plan	\$130,079	\$176,337	\$192,652

ATTACHMENT 'A'

RESEARCH PRESSURE INSTRUMENTATION
FOR
NASA SPACE SHUTTLE MAIN ENGINE
HONEYWELL, INC.

1.0 . Introduction and Objective

The first phase of this contract (Tasks A and B) resulted in a highly successful demonstration in April 1983 at the MSFC of Honeywell's breadboard feasibility model of a silicon Piezoresistive Pressure Transducer suitable for SSME applications.

The purpose of Modification No. 5 of this contract is to expand the scope of work (Task C) of this research study effort to develop pressure instrumentation for the SSME. The objective of this contract (Task C) is to direct Honeywell's Solid State Electronics Division's (SSED) extensive experience and expertise in solid state sensor technology to develop prototype pressure transducers which are targeted to meet the SSME performance design goals and to fabricate, test and deliver a total of 10 prototype units.

SSED's basic approach is to effectively utilize the many advantages of silicon piezoresistive strain sensing technology to achieve the objectives of advanced state-of-the-art pressure sensors in terms of reliability, accuracy and ease of manufacture. More specifically, integration of multiple functions on a single chip is the key attribute of this technology which will be exploited during this research study.

The objectives of this research study will be accomplished by completing the following major tasks:

1. Transducer Package Concept and Materials Study

Three transducer design concepts will be generated and analyzed for the SSME application and materials/processes will be defined for the research prototype transducer design.

2. Silicon Resistor Characterization at Cryogenic Temperatures

The temperature and stress properties of a matrix of ion implanted piezoresistors will be characterized over the temperature range of -320°F to +250°F.

3. Experimental Chip Mounting Characterization

The mechanical integrity of chip mounting concepts will be evaluated over temperature, pressure and vibration.

4. Frequency Response Optimization

This task is a paper study which will specify and analyze an acoustic environment for which transducer frequency response can be determined and optimized.

5. Prototype Transducer Design, Fabrication, and Test

This major task will use the results generated in Tasks 1 through 4 above to design and develop a research prototype pressure transducer for the SSME application and will culminate in the delivery of 10 transducers, 5 each for the ranges of 0 to 600 psia and 0 to 3500 psia. This task is subdivided into the following five areas:

- Feasibility Evaluation of Transducer Concept
- Prototype Transducer Design
- Prototype Transducer Fabrication and Test
- Prototype Qualification
- Prototype Delivery.

6. Reports

Honeywell will submit monthly progress reports during the period of the contract; a final report will be provided at the completion of the contract.

The format of this report will be to discuss the work performed for this reporting period and the plans for the next reporting period for each of the major tasks outlined above.

2.0 Work Performed and Plans

In addition to the progress reported below, preparations were started in support of the six (6) month Program Review scheduled for 4/12/84 at NASA/MSFC.

2.1 Transducer Package Concept and Materials Study

This task was completed per plan during January 1984.

2.2 Silicon Resistor Characterization at Cryogenic Temperatures.

2.2.1 Work performed in March.

Testing of the "floating" chip and TE bonded test samples was completed over the temperature range of -40°C to -120°C. The test data has been reduced and plotted. Attachment 'C' contains some typical examples of the data collected for each sample configuration and the dose levels being studied. Additional data reduction and analysis is required before the final dose selection is made. Some of the key trends to note are:

2.2.1 Work performed in March (Continued)

- The sensor null shift characteristic for a "floating" chip is quite different than for a chip TE bonded to a pyrex tube.
- The span shift and normalized resistance curves are monotonic in this temperature range and have shapes of opposite polarity. These too are influenced by the implant dose level. The impact of the dose is greater for the TCR than it is for span shift.

The helium cryostat was delivered during this reporting period. It has been set-up and the debug process started. We are encountering some problems with a heater in the cryostat, namely, burn-out. The life of the first two was unusually short. The net result is that the cryogenic testing schedule is being adversely impacted. See Section 3.0 for more discussion.

2.2.2 Plans for April

The plans are as follows:

- Complete the debugging of the helium cryostat.
- Start the characterization of the test samples at cryogenic temperatures.
- Reduce and display the results from this characterization testing in support of selecting a dose for the feasibility sensor design.
- Select the implant dose to be used in the feasibility sensor design.

2.3 Experimental Chip Mounting Characterization

2.3.1 Work performed in March

The design of the following pieces of sensor hardware was completed for Concept #5 during this reporting period:

- Stainless Steel Housing (except for the mounting details for the electrical connector. These details are pending receipt of connector prints from Deutsch Connector Co.)
- Stainless Steel Base
- Silicon Nitride Terminal Boards 1 and 2.
- Pyrex Cover Glass for laser trimming.
- Invar Mounting Plate
- "V" - Ring seal

The fabrication of the above hardware was started. The status of this activity is summarized below.

- Stainless Steel Housing and Base.
 - Stainless steel material has been ordered.
- Silicon Nitride
 - Quote received from Kyocera with 9-10 week delivery.
 - Kyocera's literature reports their hot pressed material has a porosity of ~ .1%. The impact of this parameter is not clear and is being evaluated further.
- Invar Mounting Plate
 - Invar (Alloy 36) material has been ordered.
- "V" - Ring
 - Received a quote from Advanced Products with 11 week delivery. We are negotiating for a better schedule.

Regarding the development of assembly processes for Concept #5, the activity during this reporting period focused on attaching the sensor chip to silicon nitride and on achieving a silicon nitride-silicon nitride-pyrex "sandwich". Three approaches were evaluated for attaching the silicon sensor chip to silicon nitride. Of the three, only one has a reasonable probability of being successful. This approach uses TE bonding to join the sensor chip to a pyrex washer and a solder bond to join the sensor/pyrex assembly to the silicon nitride. The solder bond is at the pyrex-silicon nitride interface. Some of the key features of these joints are as follows:

- TE bond (silicon to pyrex): requires optically flat surfaces.
- Interface metallization (pyrex-silicon nitride): Ti/Pt/Au -- both surfaces.
- Solder: Au/Ge

The integrity of these joints was evaluated using the following temperature shock testing profile:

- (-200°C) to 100°C: Five times
- (-255°C) to 25°C: Once (more planned)

The post-test evaluations showed no apparent damage to the joints. More testing/evaluation is required, however.

The foregoing sandwich structure was modeled using finite element methods to determine the impact of solder creep on sensor performance. This analysis shows that changes in stress due to solder creep can be transmitted to the sensor chip. However, this effect can be minimized by using a solder that has a high resistance to creep. Because of the high strength properties of the Au/Ge solder, it is expected it will have a high resistance to creep. This may, however, require some critical experiments to verify the magnitude of this effect.

The difficulty with the other two approaches for joining silicon to silicon nitride was that with or without a sputter-deposited pyrex film on the silicon nitride the required optical flatness could not be achieved. The net result was that a TE bond could not be made.

A soldering approach was evaluated for fabricating the silicon nitride-silicon nitride-pyrex (laser window) "sandwich" structure. The test results to-date show that it too has a reasonable probability of being successful. Some of the key features of the solder joints are as follows:

- Interface metalization (all parts): Ti/Pt/Au
- Solder (silicon nitride-silicon nitride): Au/Ge
- Solder (silicon nitride-pyrex): Pb/Sn/Ag

As with the other "sandwich" structure, the integrity of these joints was evaluated using temperature shock testing using the same test profile as noted above. The post-test results were also the same, i.e., no apparent damage to the joints.

The fabrication of some nonfunctional "sensor" chips (i.e., raw silicon chips without piezoresistors) was completed in support of the assembly process development activity.

2.3.2 Plans for April

The plans are as follows:

- Receive prints for electrical connector from Deutsch Convertor Co.
- Complete design of Stainless Steel Housing.
- Complete design and start the fabrication of these test fixtures:
 - Vibration testing
 - High pressure testing
 - High pressure leak checking

2.3.2 Plans for April (Continued)

- Complete some additional finite element modeling to evaluate some alternative sensor mounting schemes that circumvent the impact of Au/Ge creep discussed in Section 2.3.1. Two alternatives are of interest, namely, replace both silicon nitride pieces with undoped silicon or a combination of undoped silicon and pyrex. These two structures plus the current baseline are sketched in Attachment 'D'.
- Complete fabrication of Stainless Steel Housing and Base.
- Complete fabrication of INVAR Mounting Plate.
- Order "V" Ring and silicon nitride.

2.4 Frequency Response Optimization

This task was completed per plan in February 1984.

2.5 Temperature Sensor Network Concept Study.

This task was deleted when the contract was negotiated.

2.6 Prototype Transducer Design, Fabrication and Test

2.6.1 Feasibility Evaluation of Transducer Concepts.

2.6.1.1 Define/Finalize Concept for Feasibility Transducer.

.1 Work performed in March

A source for thick silicon wafers was identified. The delivery schedule ranges from six (6) to eight (8) weeks (min.) if vendor has correct ingot in his inventory to 16 weeks if vendor has to grow a special ingot.

More detailed finite element modeling was started on the Concept 5. configuration. This work focused on establishing the minimum acceptable thickness for the sensor chip. The results from the analysis suggest a minimum sensor chip thickness (other than the diaphragm) that is $> .030$ ". This condition is driven by the need to have a sufficiently rigid constraint for the diaphragm.

.2 Plans for April

The plans are as follows:

- Complete the design of the feasibility sensor chip.
- Start the layout of the sensor design in support of mask fabrication.
- Design and start the fabrication of special wafer processing fixturing to accommodate the thick silicon wafers.

2.6.1.2 "Prototype" Transducer Design

.1 Work performed in March

Acoustic design considerations were continued under this task during this reporting period. (Re: February Monthly Report). Consideration was given to exploring ways to damp out or reduce the impact of the undesirable acoustic resonances reported previously. The approach taken was to study the effect of using side ports oriented 90° relative to the sensor housing axis. The key conclusions developed are as follows:

- A Helmholtz type side-port structure is needed to reduce the amplitude of acoustic resonances in the 0 - 10KHz range.
- Simple, straight tube side ports cannot be used because the allowable tube lengths give resonances at frequencies > 10KHz.
- Attachment 'E' contains some frequency response characteristics that illustrate the impact of using a Helmholtz side-port resonator.

.2 Plans for April

The plans are as follows:

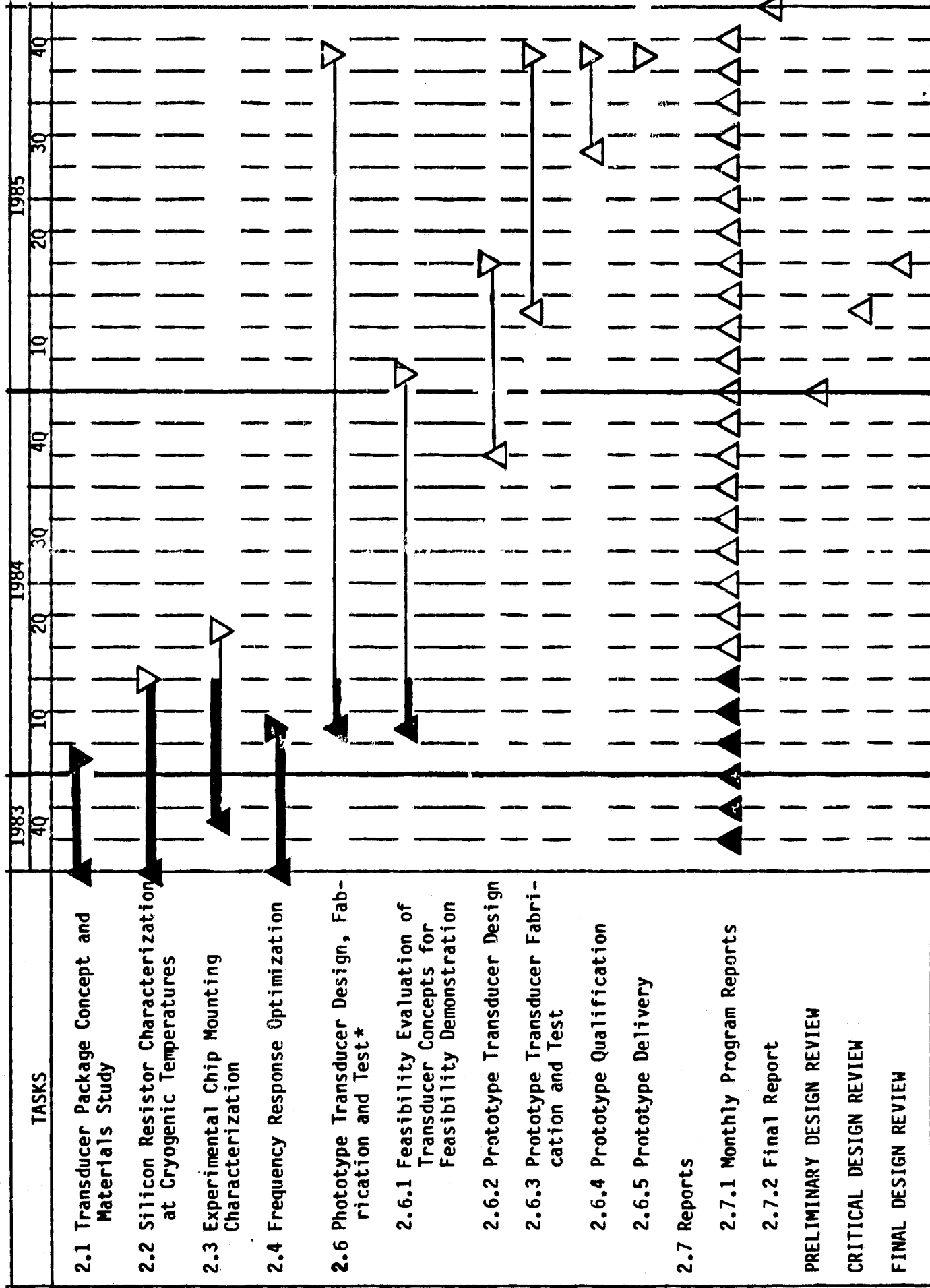
- Define the most promising plumbing configuration between the sensing port and the sensor, and generate frequency response characteristics for gaseous H₂ and O₂ as a function of temperature.
- Develop design guidelines for the use of side-ports to reduce the amplitude of acoustic resonances.

PAGE EIGHT

3.0 Schedule -- See Attachment 'B'.

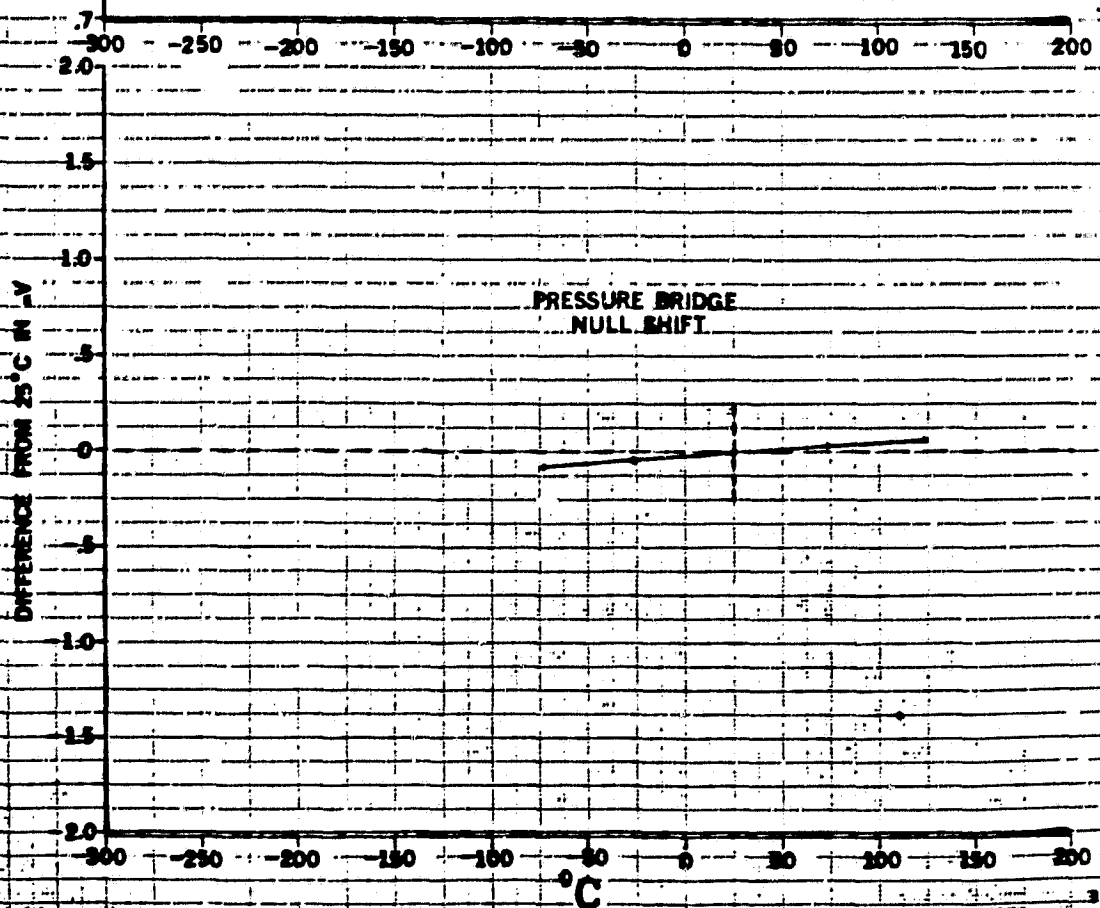
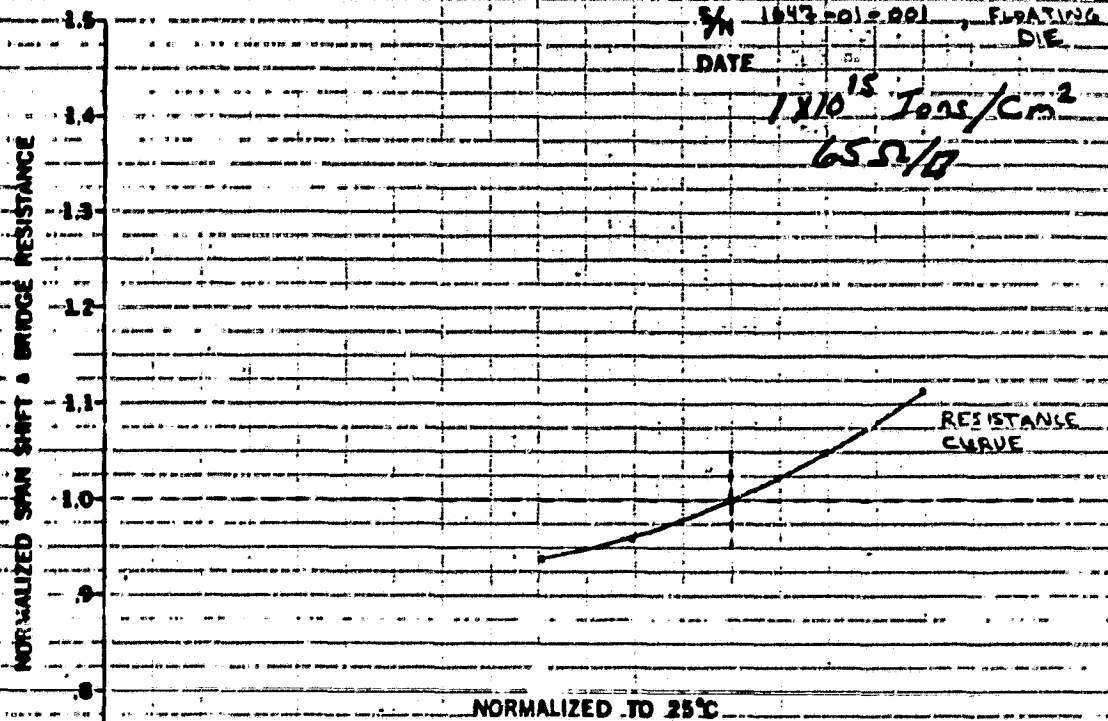
The task for characterizing silicon piezoresistors was not completed per plan. The limiter has been the performance of the helium cryostat. We are working with the equipment vendor to resolve the cryostat performance problems. A revised date for task completion will be provided in our April report. This delay is not adversely impacting the design of the feasibility sensor chip because we will, if necessary, use the -40° to 100°C data acquired to-date to satisfy this input to the feasibility sensor chip design.

RESEARCH PRESSURE INSTRUMENTATION FOR NASA SPACE SHUTTLE MAIN ENGINE SCHEDULE



* 12/83: Numbering changed to retain numbering in original proposal. Task 2.5 was deleted during contract negotiations.

NASA CRYOGENIC TESTING



NASA CRYOGENIC TESTING

S/N 1647-09-001 FLOATING
DATE DIC

1.85×10^{15} Ions/cm²
50 Ω /u

NORMALIZED SPAN SHIFT & BRIDGE RESISTANCE

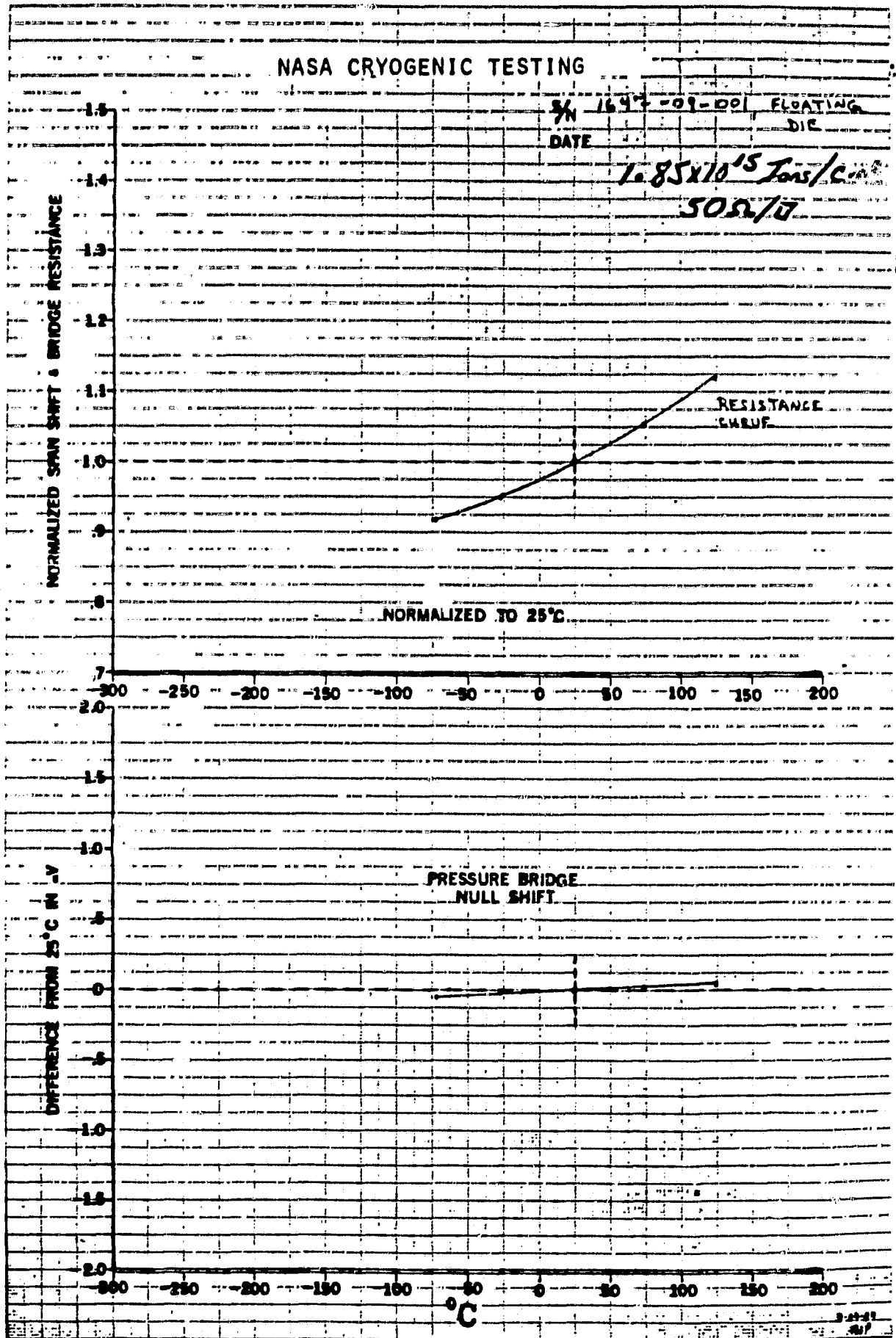
RESISTANCE
CURVE

NORMALIZED TO 25°C

DIFFERENCE FROM 25°C IN .V

PRESSURE BRIDGE
NULL SHIFT

°C



NASA CRYOGENIC TESTING

SN 1647-13-002, FLOATING DIE

DATE

$2.80 \times 10^5 \text{ TONS/cm}^2$

$35 \Omega/\Omega$

NORMALIZED SPAN SHIFT & BRIDGE RESISTANCE

RESISTANCE
CURVE

NORMALIZED TO 25°C

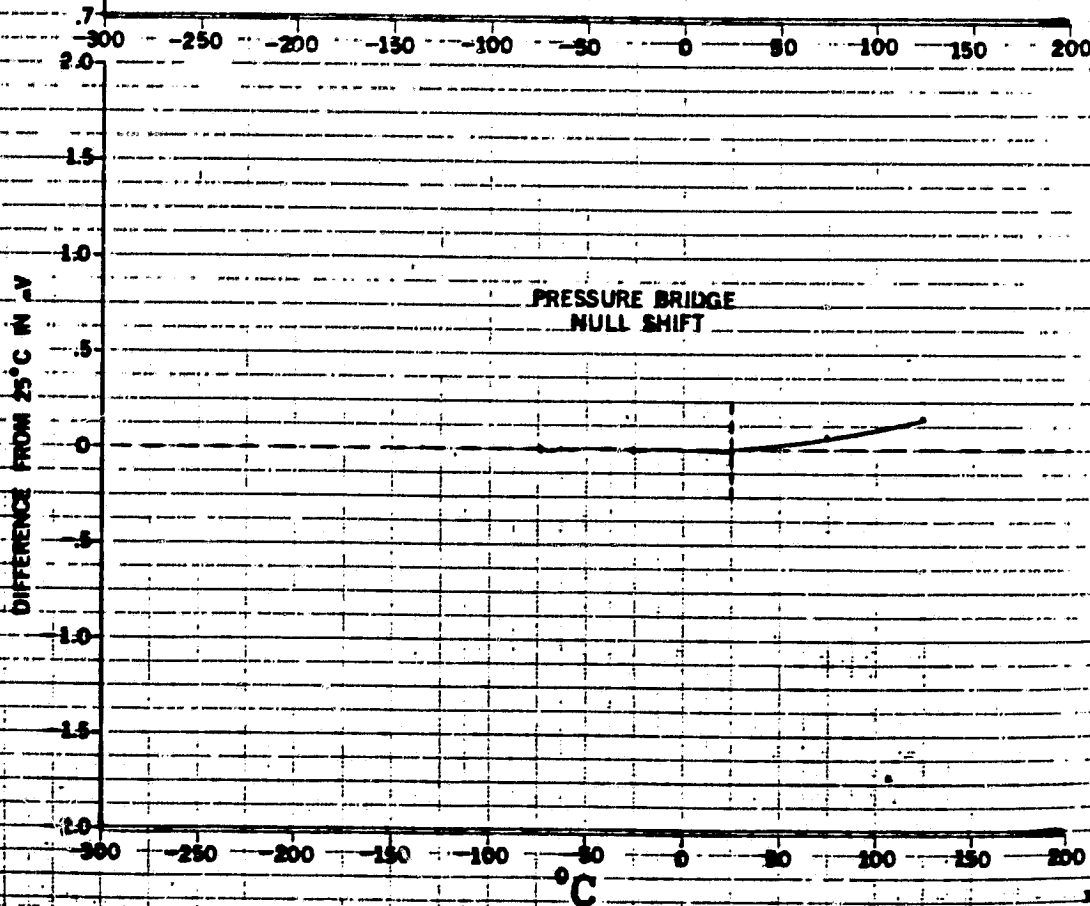
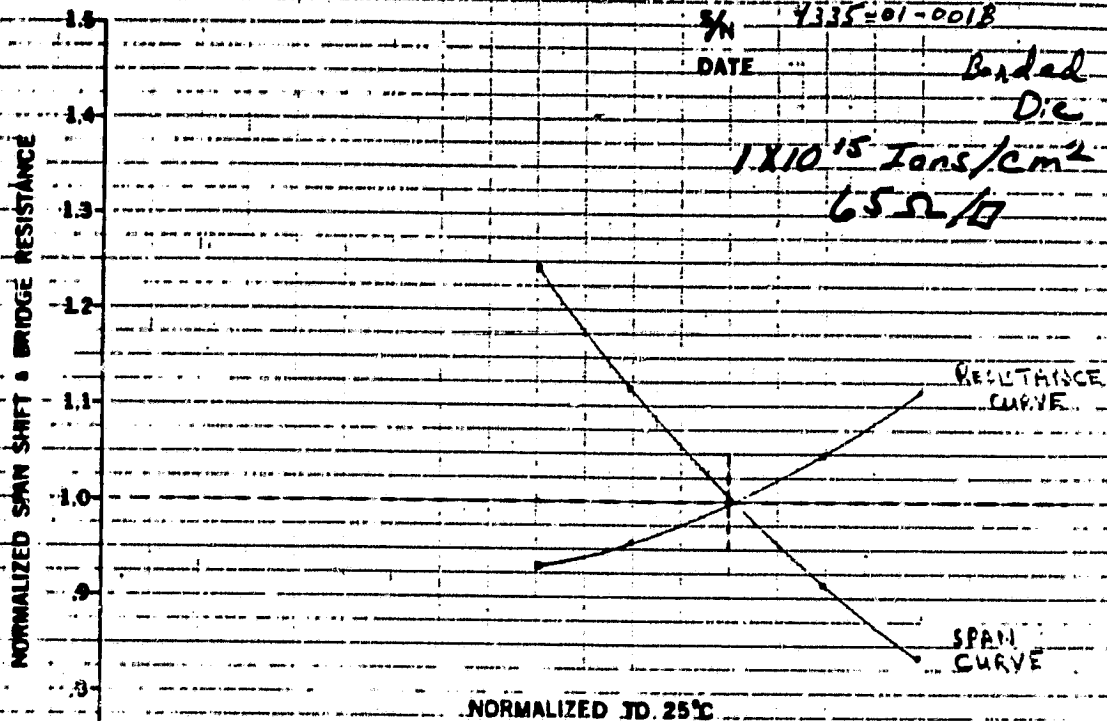
DIFFERENCE FROM 25°C IN ΔV

PRESSURE BRIDGE
NULL SHIFT

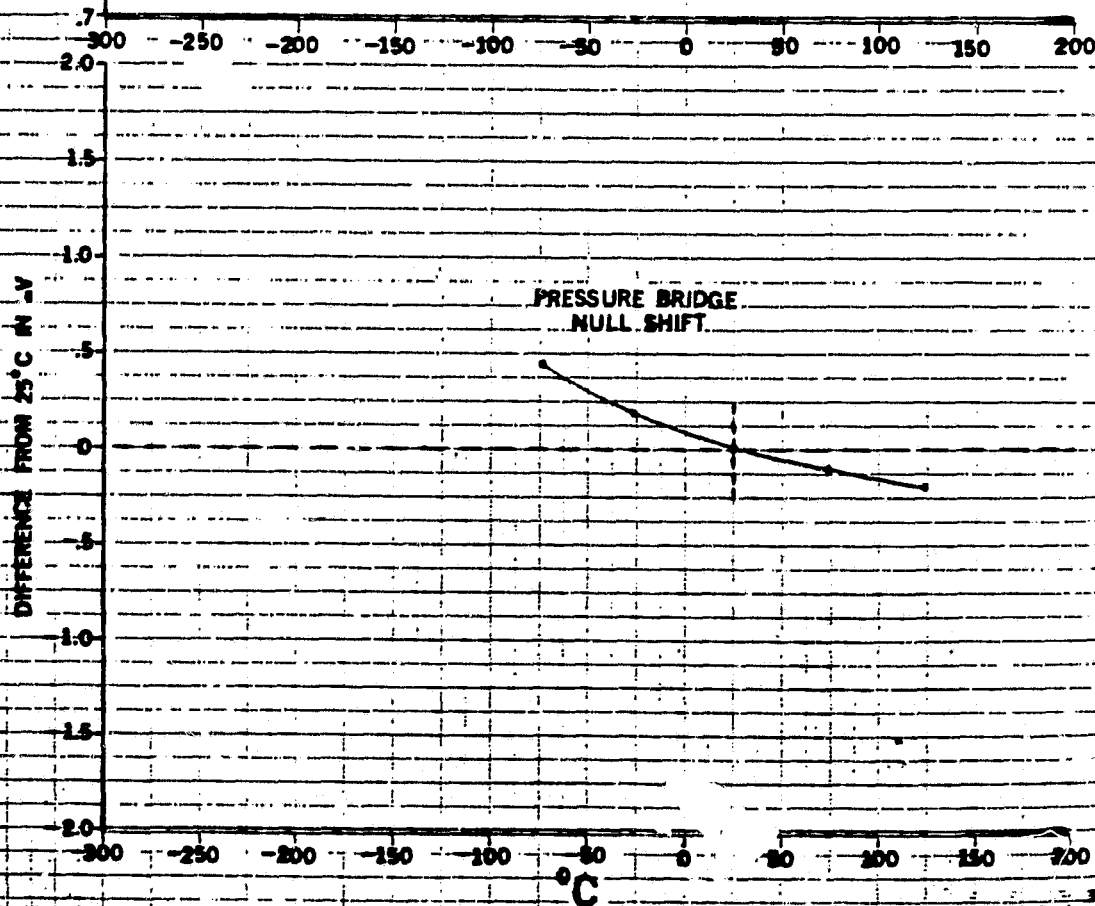
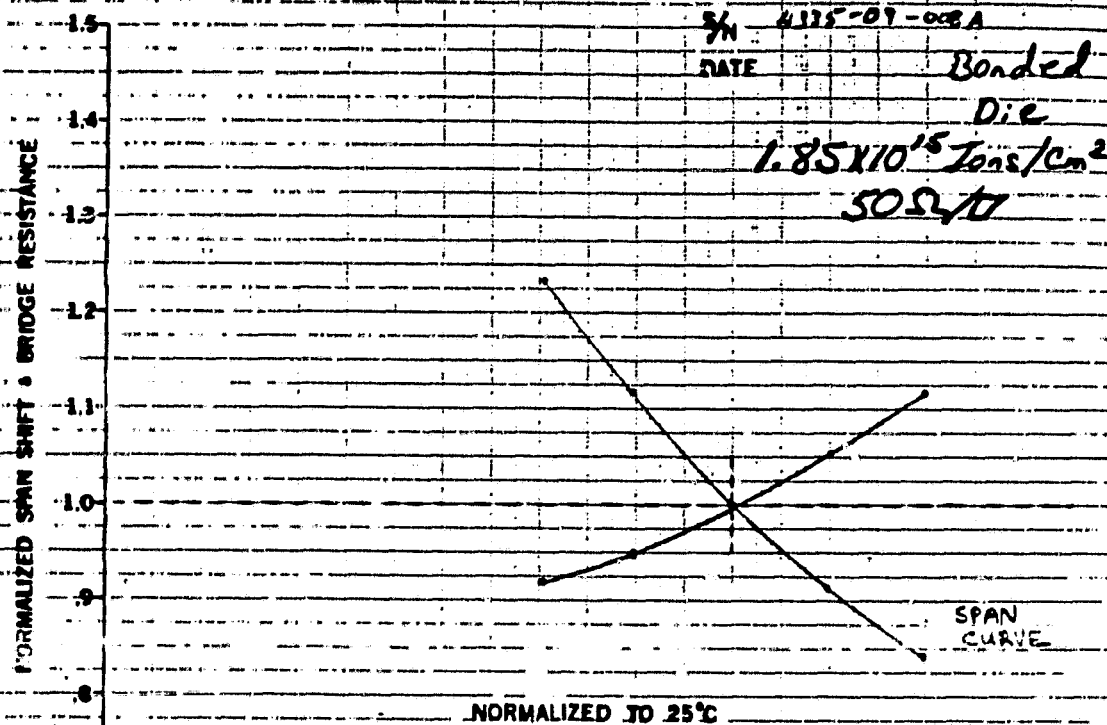
°C

3-23-61
417

NASA CRYOGENIC TESTING



NASA CRYOGENIC TESTING



NASA CRYOGENIC TESTING

S/N

4335-13-006A

DATE

Bonded

D.C.

 $2.80 \times 10^{-5} \text{ } \Omega/\text{cm}^2$

35.0/17

NORMALIZED SPAN SHIFT & BRIDGE RESISTANCE

1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7

NORMALIZED TO 25°C

RESISTANCE
CURVESPAN
CURVE

300 -250 -200 -150 -100 -50 0 50 100 150 200

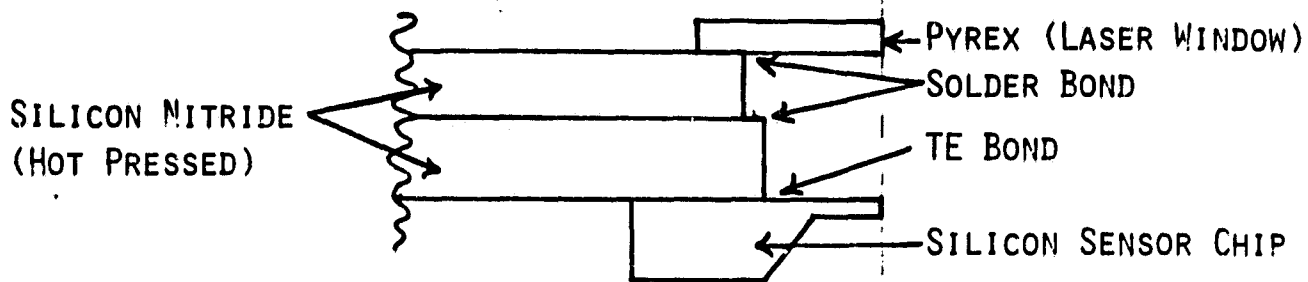
DIFFERENCE FROM 25°C IN μV 1.5
1.0
0.5
0
-0.5
-1.0
-1.5
-2.0PRESSURE BRIDGE
NULL SHIFT

300 -250 -200 -150 -100 -50 0 50 100 150 200

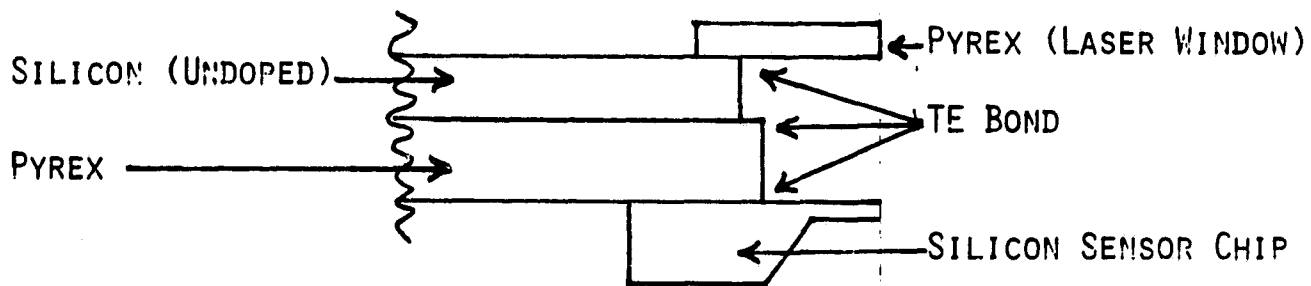
 $^{\circ}\text{C}$

ATTACHMENT "D"

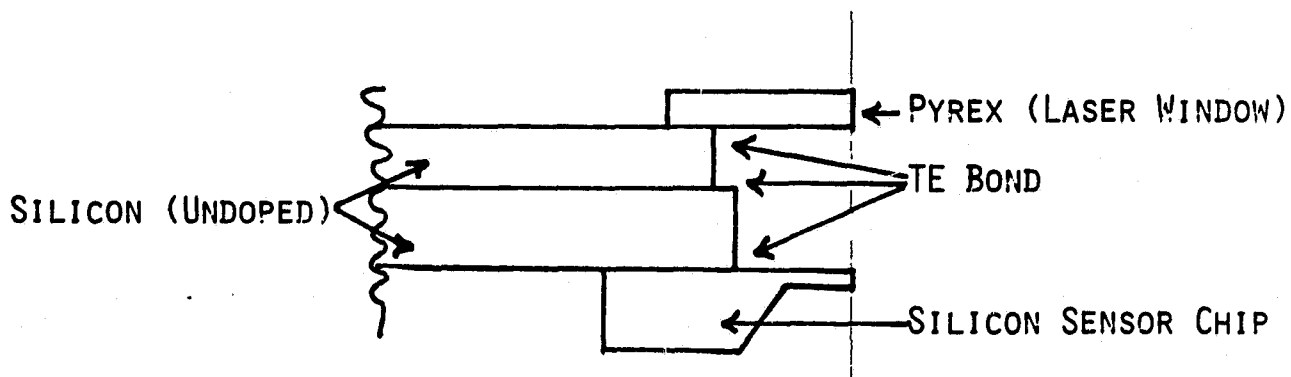
ORIENT. POINT 17
OF POOR QUALITY



BASELINE MATERIALS CONFIGURATION
(CONCEPT # 5)

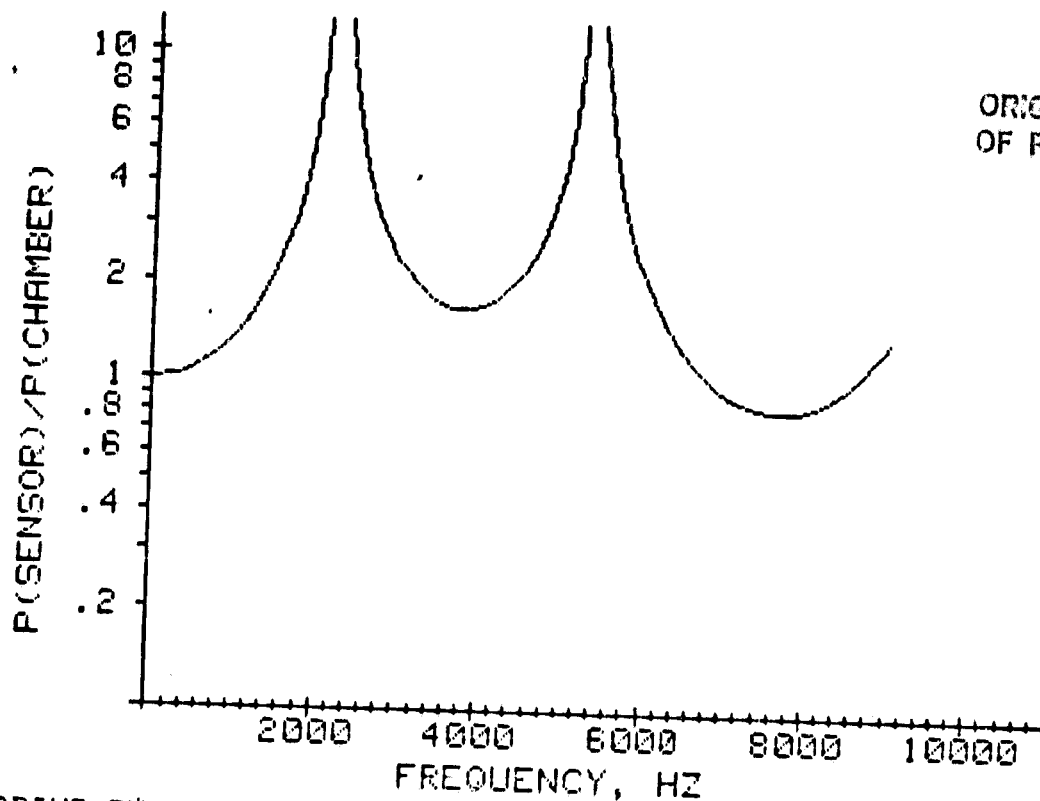


ALTERNATE MATERIALS CONFIGURATION (A)



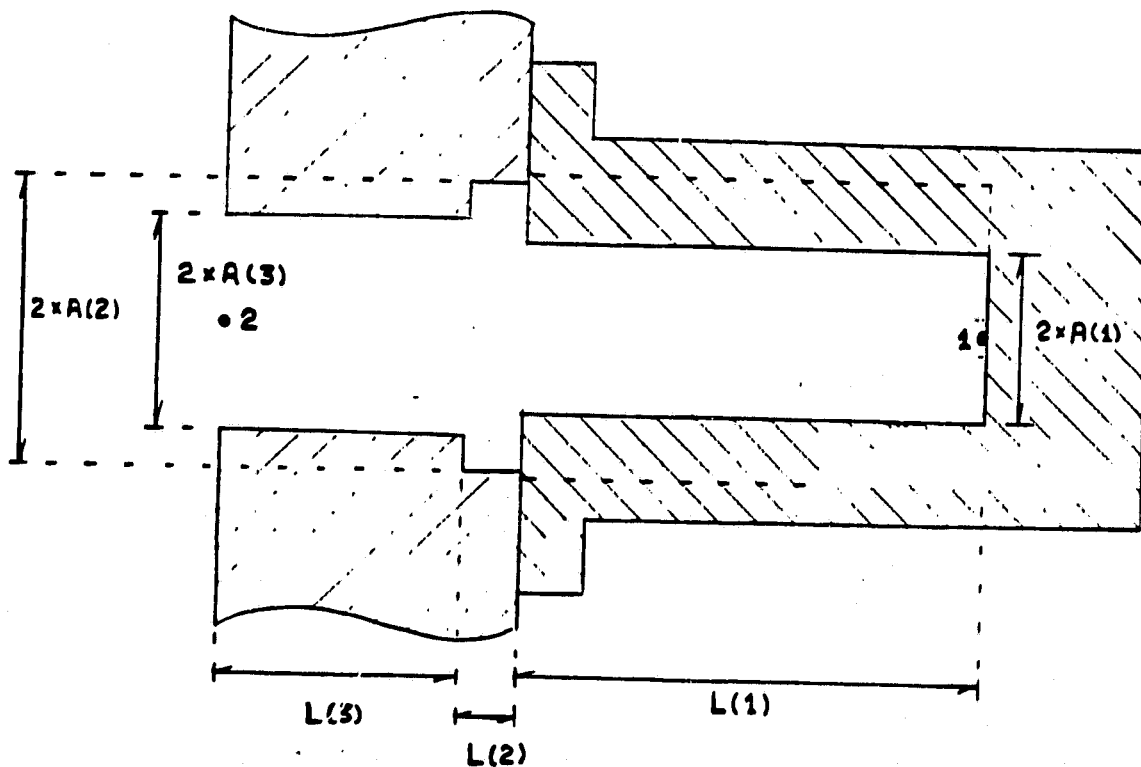
ALTERNATE MATERIALS CONFIGURATION (B)

ATTACHMENT "E"



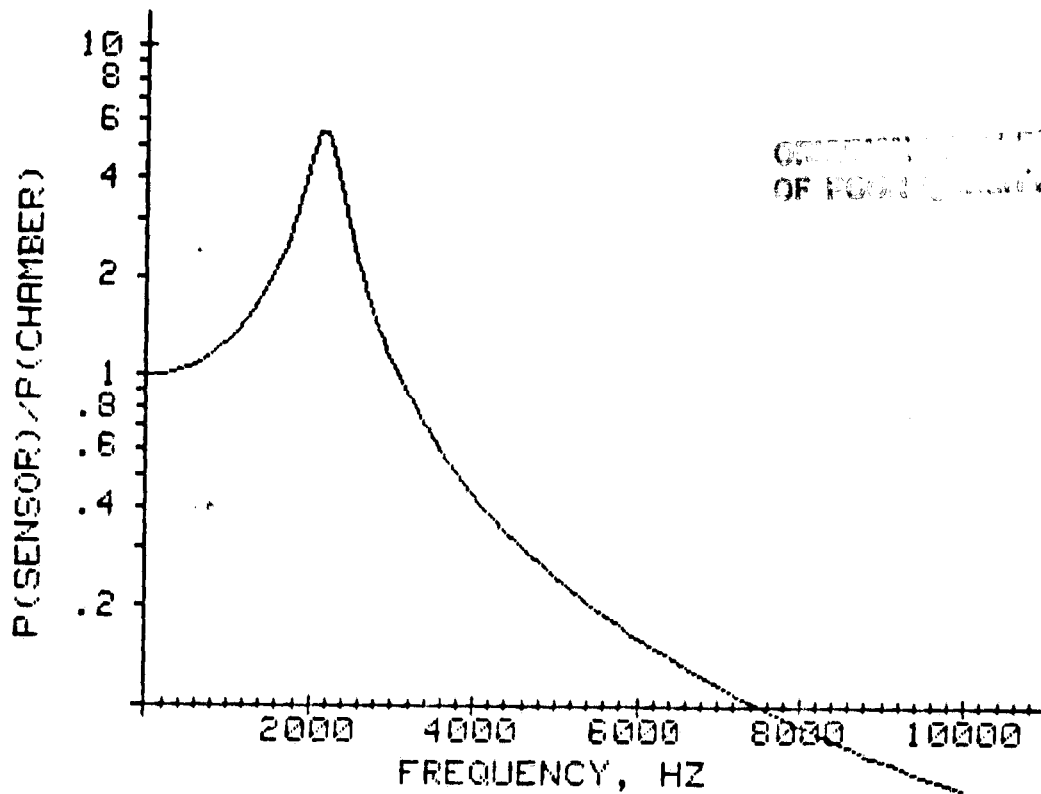
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A(2) = .762
A(3) = .559

LENGTH, CM
L(1) = 2.425
L(2) = .305
L(3) = 1.27



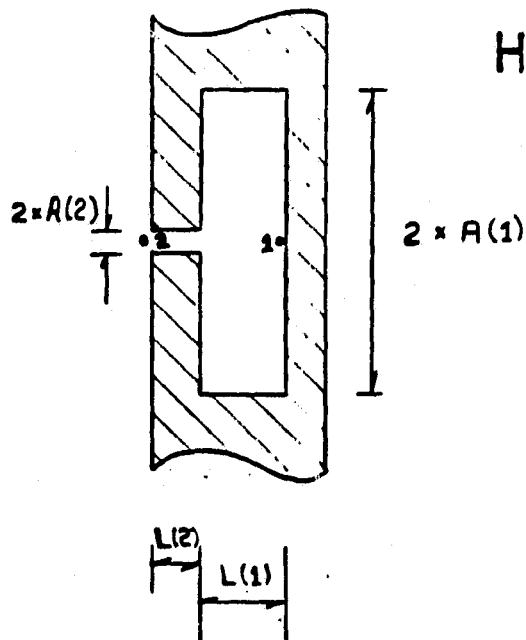
$P(\text{SENSOR}) = \text{ACOUSTIC PRESSURE AT POINT 1}$
 $P(\text{CHAMBER}) = \text{ACOUSTIC PRESSURE AT POINT 2}$

ATTACHMENT "E"



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 $A(2) = .03$

LENGTH, CM
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 $L(2) = .125$

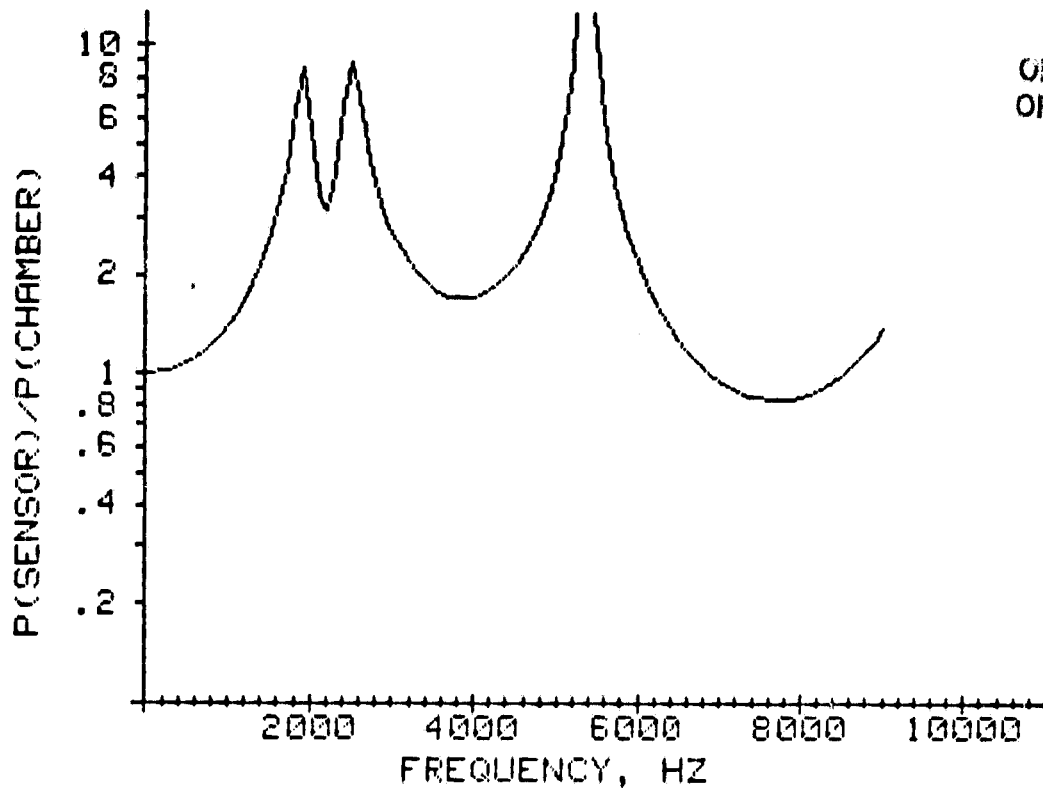


HELMHOLTZ RESONATOR

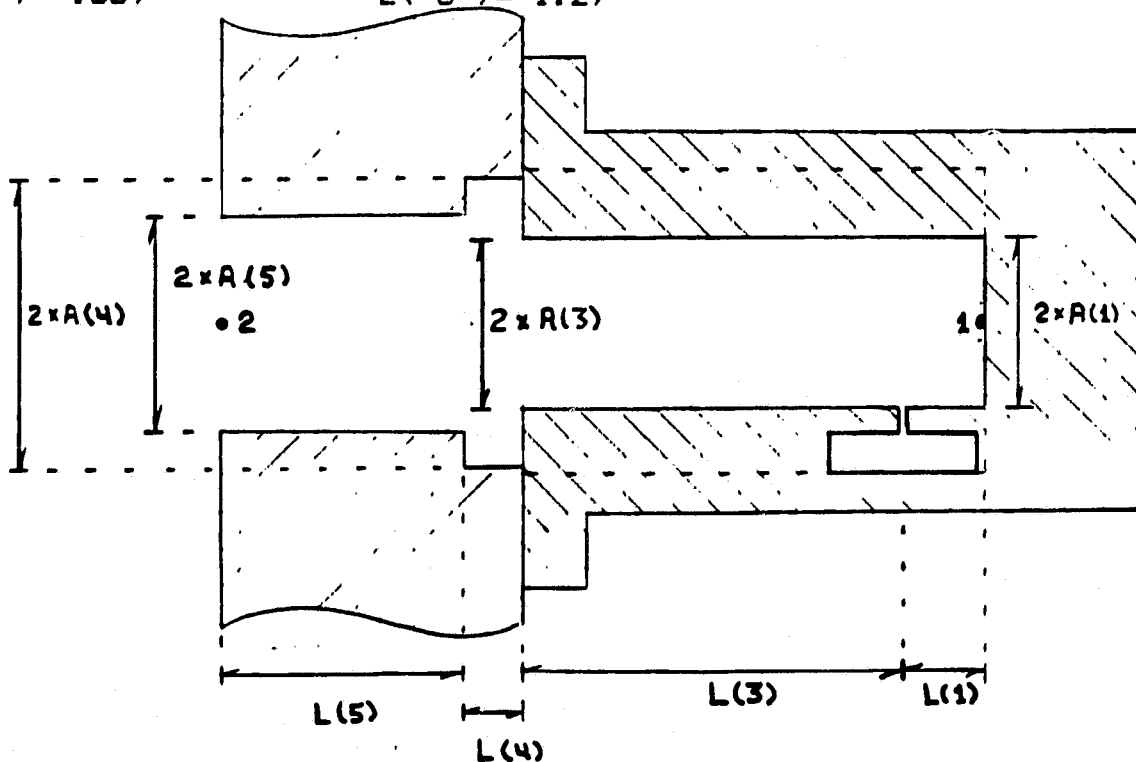
$P(\text{SENSOR}) = \text{ACOUSTIC PRESSURE AT POINT}$

$P(\text{CHAMBER}) = \text{ACOUSTIC PRESSURE AT POINT}$

ATTACHMENT "E"



RADIUS, CM	LENGTH, CM
A(1) = .451	L(1) = .425
A(3) = .451	L(3) = 2
A(4) = .762	L(4) = .305
A(5) = .559	L(5) = 1.27



$P(\text{SENSOR}) = \text{ACOUSTIC PRESSURE AT POINT 1}$

$P(\text{CHAMBER}) = \text{ACOUSTIC PRESSURE AT POINT 2}$